HOW TO CALCULATE BUDGET RESERVE FOR YOUR PROJECT

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Overruns happen!
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PRESENTATION TOPIC

No industry, including aerospace and NASA in particular, has an accepted process for calculating budget reserve for projects.

Most projects select budget reserve at a level that is expected to be acceptable to the sponsor and not based on engineering calculation. Most projects tend to vastly overrun this artificial reserve.

The first part of this presentation describes the reserve calculation method called McRisk which factors in the amount of technical and programmatic risk of a project. The second part illustrates the different aspects of McRisk in a case study.

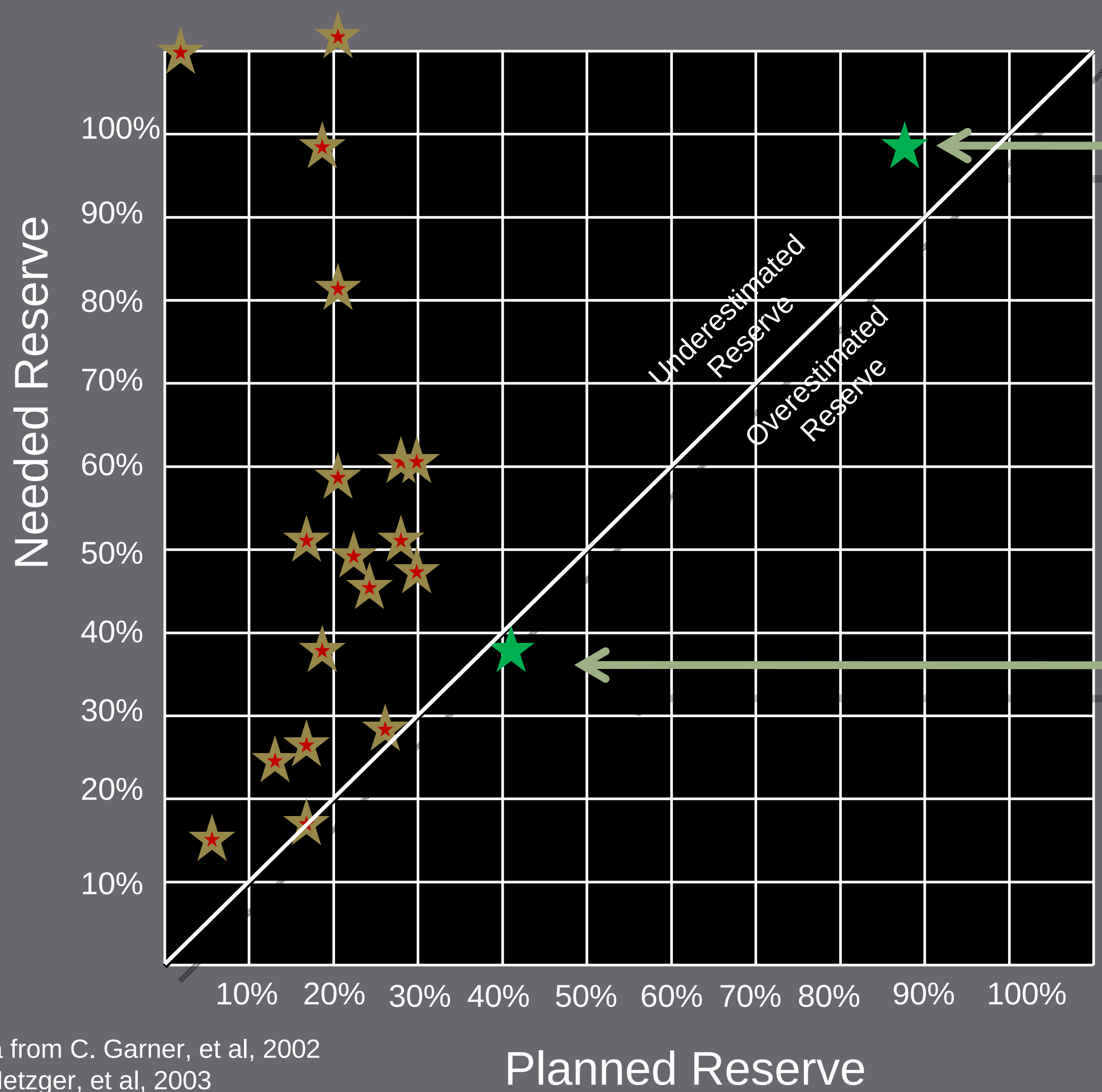
Most Projects Overrun the Reserves

Mission type	# of Missions Studied	Reserve under-estimated by
Flagship (> $800M)	4	164%
Medium size (< $300M)	5	19%
Large Instruments (< $150M)	2	34%
System Technology Experiments (< $150M)	3	131%
Technology Experiments (<$25M)	11	107%**
Small Technology Experiments (<$5M)	13	315%**

- Reserve estimation errors are very high with exception of medium size missions
- Reserve estimation accuracy has not improved in the last 20 years
- Reserve errors are not limited to one organization, center, type of mission
- Only 3/38* missions did not exceed the budget reserve allocation
- Only 1/38 missions used a strict process to calculate the amount of needed reserve

* 38 missions consisted of: 11 microgravity experiments, 13 In-Step experiments, 14 other NASA missions
** No reserve was planned for most technology experiments

Great Majority of Missions Exceed the Budget Reserve



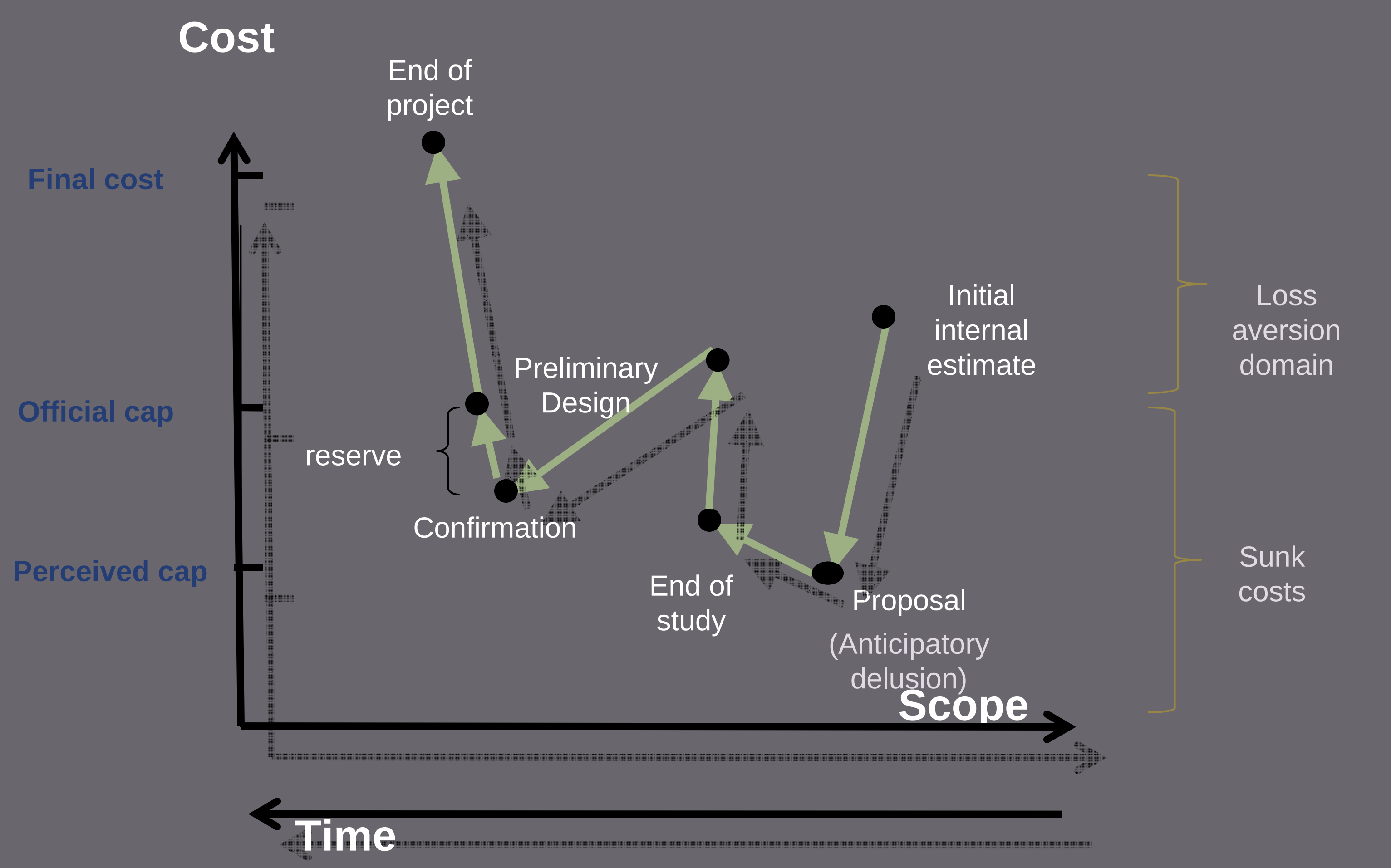
Our case study - Great Gadget

Another project Using McRisk

Legend:
- NASA mission not using McRisk
- McRisk mission

Data from C. Garner, et al, 2002
R. Metzger, et al, 2003
R. Schmitz, 1991

Project "W" Curve



Dr. D. Ullman, Making Robust Decisions, 2006

What is a "W" Curve?

- **Most projects' costs follow a "W" curve:**
  - The cost estimates usually start with an internal organization's cost estimate which frequently is deemed too high by the management.
  - The management instructs the team to remove some scope and cut the cost below the perceived sponsor's threshold.
  - A proposal is prepared showing this low cost and low risk. Frequently the reserve is shown to be 10-30%. The management and the team are very optimistic about the cost performance. (Psychologists call this anticipatory delusion.)
  - At the end of the initial study the cost estimate goes up and more scope is removed to stay under the perceived cap. The project is confirmed for the design phase with 10-30% budget reserve.
  - The project overruns but is allowed to continue because what economists call "loss aversion". The sponsor does not want to lose the benefit of "sunk costs" and increases the project cap.

Origins of McRisk

- In 2002 one of the authors became the manager of a project consisting of 3 space technology experiments – a type of mission which is legendary for huge overruns. To learn from past history the authors analyzed cost performance of 24 NASA new technology space experiments*. The cost data were studied to find the most common culprits for overruns and eliminate them from the current project.

- Data showed 2 primary reasons for project overruns:
  1. **Poor cost estimating.** In response to this conclusion, a study** was initiated on how to improve cost estimating techniques. The results of this study were shown at the Management Forum in 2004.
  2. **Budget reserves grossly incompatible with risk.** This conclusion was dealt with by developing a reserve estimating technique dubbed McRisk.

*"Microgravity Flight Projects Cost Study Report Summary", C. Garner, A.B.Chmielewski, January 2002
**"Improving Project Cost Estimates", D. Ullman, D. Persohn, A.B.Chmielewski, L. Leach, 2003

McRisk Applications

- McRisk (Monte Carlo Risk) is a technique which allows calculating the amount of needed budget reserve commensurate with risk of the project.

- The technique was used to calculate the budget reserve of 7 space experiments.
  - One has been completed within its budget reserve
  - One has been completed and presented in this study
  - Four have yet to be launched
  - One was cancelled

- Over the 5 years of the Project life-cycle the authors collected cost data on technical risks, programmatic risks, risks predicted, risks mitigated, risks materialized, schedule delays, new technology problems, engineering problems, management problems, carrier problems, cost uncertainty and unknown unknowns. The data were collected and analyzed in a joint, cooperative NASA/JPL/contractor postmortem study.

McRisk Process

The McRisk process was designed to expose most risks and cost uncertainties experienced by space missions. The process combats inherent optimism, anticipatory delusion and anchoring effects which make most missions overrun the initial cost estimates.

Verify result

Locate 80% confidence point

Create S-curve

5

Run Monte Carlo code

Build McRisk Table

4

Account for cost uncertainty and Unknown Unknowns

3

Build programmatic McRisk List

2

Build technical McRisk List

1

The next 5 charts describe McRisk process in more detail

1) Build Technical McRisk List

- **Identify ALL possible technical risks for each subsystem**
  - Use "Worry Generators" – Create a list of dozens of well known risks for software, hardware and management. Use this list in costing exercises.
  - "Brain storming" sessions – Team members speculate on risks in "rapid fire" format.
  - Comments from experts – Interview experienced project managers.
  - Comments from reviews – Document every comment at each review and add to the list.
  - Institutional past experience – Parse company's "lessons learned", management papers, magazine articles.

2) Build Programmatic McRisk List

Programmatic risks are tough to account for:

• Engineers dislike predicting programmatic risks

• Managers tend to be optimistic and believe that they will handle programmatics. “I will not let the old problems happen to my project!”

• There is some historical documentation on past technical problems but not on programmatic problems

• Many programmatic problems are created by the sponsor*

Account for programmatic risks by:

– Using Worry Generators
– Interviewing managers from outside of the project
– Putting on the team an experienced manager ready to retire
– Adding schedule risks

*E. Anderson et al, “The Success Triangle of Cost, Schedule, and Performance”, 2002

3) Account for Cost Accuracy and Unknown Unknowns

- The project cost-to-complete estimate is not one point, it is not one cell on an Excel spread sheet. The cost estimate is a range!

- Add a risk item to the table to account for cost estimate uncertainty. The uncertainty expressed in $K is a percentage of the estimated cost to complete.
  - Minimum = -5%
  - Nominal = +10%
  - Maximum = +15%

- Unknown Unknowns can be assumed to be a percentage of the cost to go and added as a risk item. This amount depends on how thorough is the risk identification effort. 10-15% should be used even for the most diligent risk identification process.

4) Build McRisk Table

- Grouping the risks helps to reduce complexity
  - 232 risks were listed and coalesced into 54 for Great Gadget
- Establish probability of occurrence for each risk
- Estimate the minimum, nominal and maximum impact in $K if the risks were to materialize

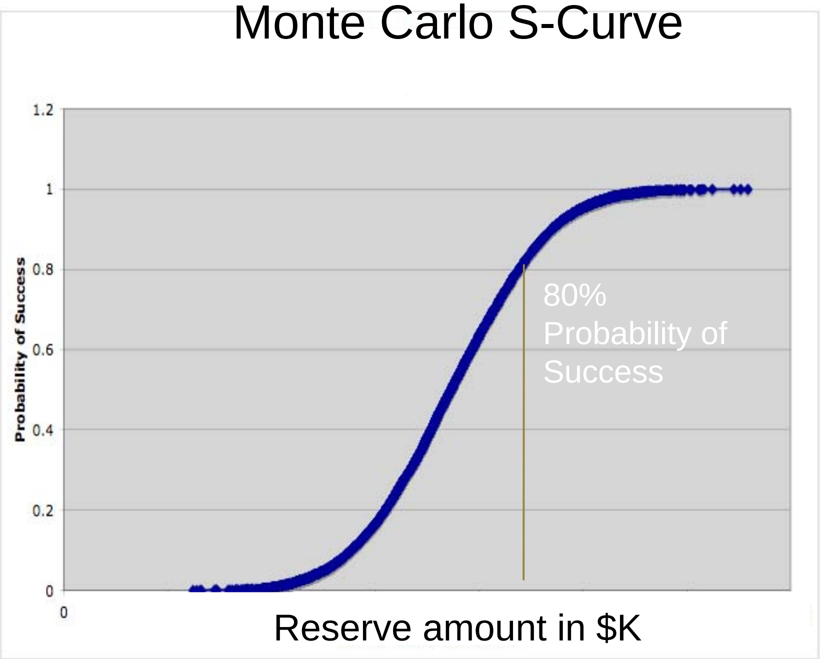
Example of One Row of McRisk Table

Not shown: consequence rating, consequence description, mitigation plan, risk to schedule and risk retirement date

Risk Item	Risk Name	Risk Description	Probability %	Cost to Mitigate Min $K	Cost to Mitigate Most Likely $K	Cost to Mitigate Max $K	Risk to Reserves* $K
16	Parts Costs	Low volume purchase, minimum buys, parts failures result in increased parts costs	80	50	125	125	100

*Risk to reserves=probability x most likely cost to mitigate

5) Create S-curve



- Run Monte Carlo code using the McRisk table and create an S-curve. The MC code performs thousands of trials where risk item costs are determined randomly within the min to max triangular distribution cost range specified in the McRisk table.

- The probability of the risk from the McRisk table is used to determine how frequently the cost of the given risk is included.

- Use the 80% point on the S-curve to determine the amount of reserve needed. This is the point where there is enough dollars to cover the problems that occur in 80% of the cases. (80% is a frequently used point on the S-curve in cost exercises. With experience different probability will be selected depending on the type of the mission.)

Case Study of Great Gadget

This case study attempts to illustrate the ability of the McRisk method to predict the necessary reserve. To put the focus on McRisk and not on the mission or any of its developers we called the project "The Great Gadget" instead of referring to it by its actual name.

The Great Gadget project was a good illustration of McRisk benefits and shortcomings because:

- it has already launched,
- it experienced a plethora of issues,
- it had a mix of new technology, hardware, software, testing and integration challenges.

Case Study of Great Gadget

- The Great Gadget was a $15M space technology validation experiment developed by a very capable R&D contractor. The contractor wanted to test in space its new technology for the benefit of NASA missions.
- The Gadget weighed only a few kilograms, used only a few watts and was shoe-box in size.
- The Gadget was roughly 20% system engineering, 20% mechanical, 20% electrical, 20% software and 20% management.
- 18 engineers worked on the gadget at the peak of development.
- The Gadget flew on a DOD carrier as piggy-back payload.

Gadget's Initial Reserves

- The Gadget was initially proposed by the contractor with 4% budget reserve on the cost-to-complete. In frank postmortem discussion with the contractor we heard:
  - "We did not want to show a lot of risk. It would defeat the proposal."
  - "If the sponsor wanted more reserve he could put more money into the coffers."
- 30% reserve was suggested by many NASA managers during project cost reviews.
- Based on analysis* of 22 space experiments which overran by an average of "π" (315%), the 30%, let alone 4% reserve, seemed grossly inadequate. The project desired to calculate the realistic amount of budget reserve commensurate with risk.

*A.B.Chmielewski, C. Garner, "Analysis of Space Experiments Overruns", Feb 2002

Using McRisk to Calculate Gadget's Reserve

- The Monte Carlo analysis of the table showed that the necessary level of the reserve was 89% of the cost-to-complete.
- The contractor was very worried about showing such a high project risk. The contractor reduced the risk list to 28 items which required 29% of budget reserve.
- Heated discussions took place on the subject of the right amount of reserve and its relation to perceived risk and confirmation of the project.
- The postmortem showed that out of 26 risk items removed by the contractor 60% did materialize and 40% did not.
- The actual amount of reserve that was necessary was 97% or 8% more than predicted by McRisk and 67% higher than the industry standard of 30%.

Example of Risks that Happened but Were Removed by Contractor

Risk Item	Risk Name	Risk Description	Probability %	Cost to Mitigate Min $K	Cost to Mitigate Most Likely $K	Cost to Mitigate Max $K	Risk to Reserves* $K
9	Parts Costs	Low volume purchase, minimum buys, parts failures result in increased parts costs	80	200	200	200	160
27	Memory Usage	Software does not fit into available memory	30	50	75	75	22.5

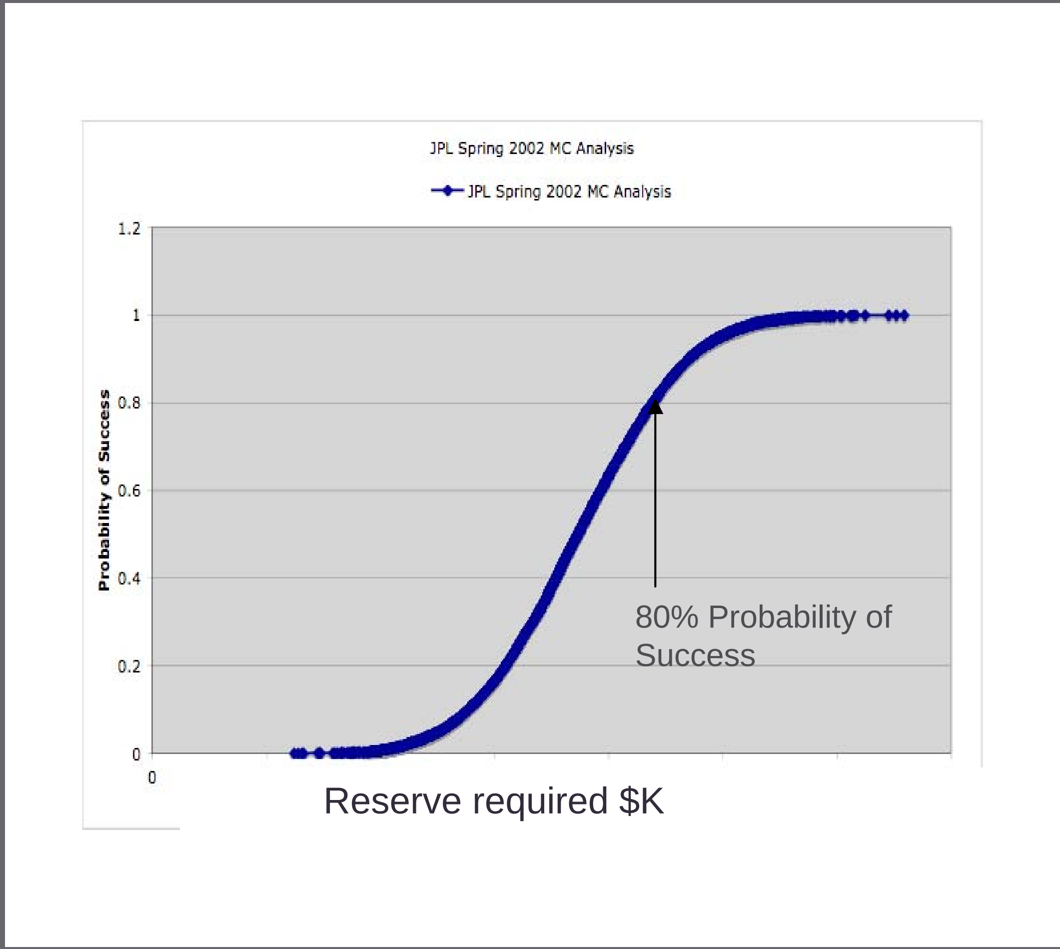
*Risk to reserves=probability x most likely cost to mitigate

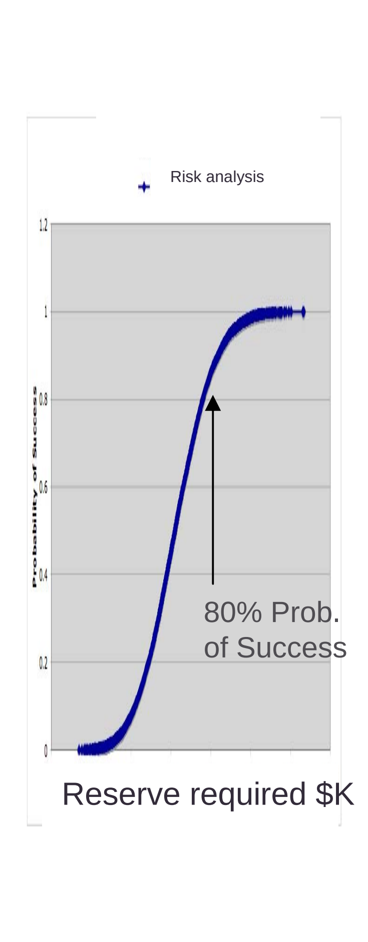
Example of Removed Risks that Did Not Happen

Risk Item	Risk Name	Risk Description	Probability %	Cost to Mitigate Min $K	Cost to Mitigate Most Likely $K	Cost to Mitigate Max $K	Risk to Reserves* $K
15	Optics misalign ment	Misalignment discovered during environmental testing	20	40	60	60	12
36	Carrier Thermal Environ ment	Analysis may be required for active thermal control	50	50	100	200	50

*Risk to reserves=probability x most likely cost

Gadget's S-curves





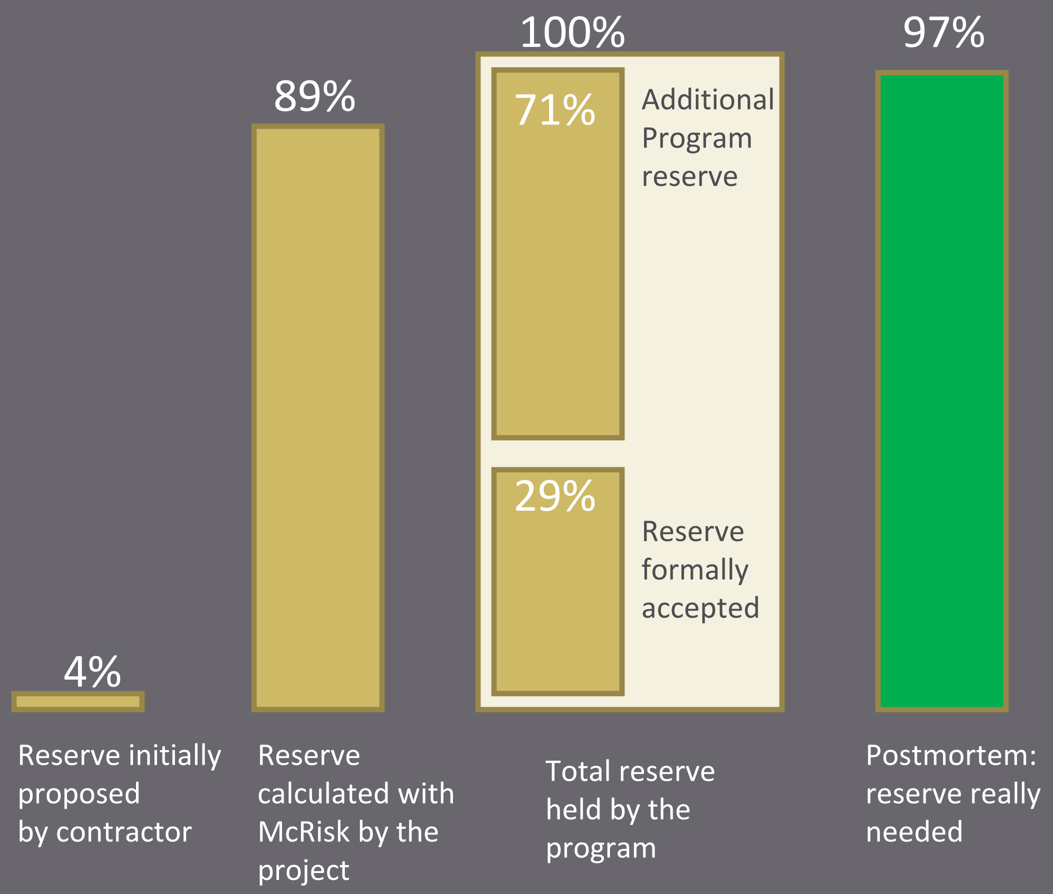
ORIGINAL JPL RISK LIST
54 ITEMS

Calculated needed reserve: 89%

CONTRACTOR'S RISK LIST
28 ITEMS

Calculated reserve: 29%

Great Gadget Reserve Story



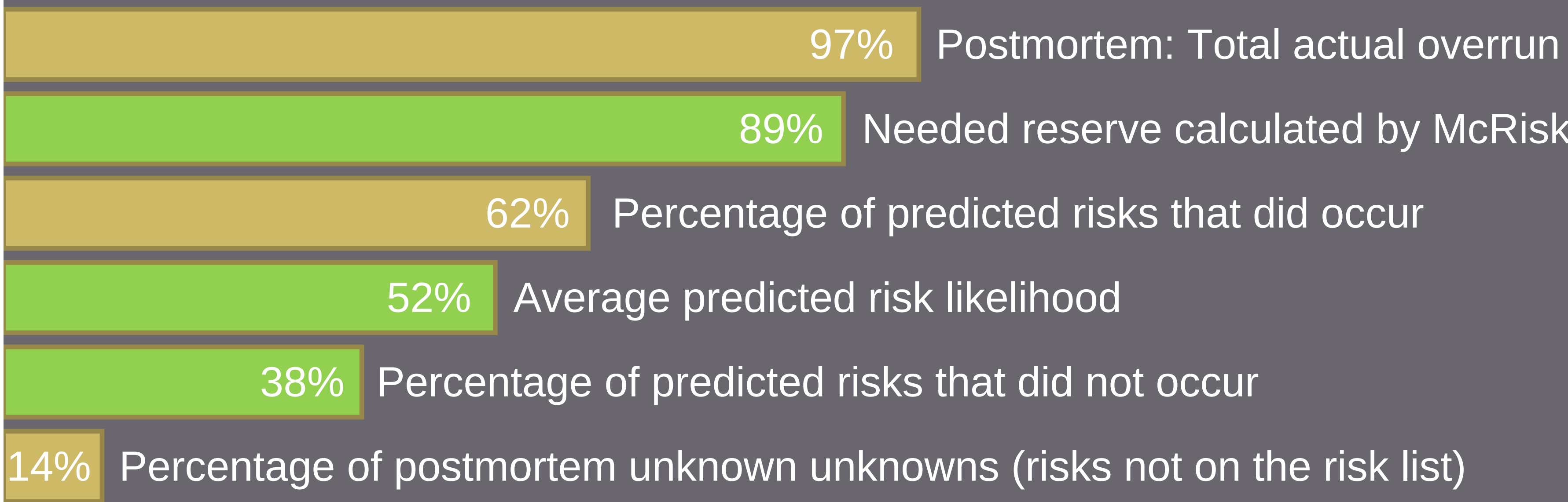
The Contractor initially proposed a 4% reserve.

The Project MCRisk calculations showed that 89% reserve would be needed.

The Contractor proposed much smaller 29% reserve based on their risk list.

A compromise was reached at the program level. 29% reserve was assigned to the project but 71% additional reserve (for a total of 100%) was held by the Program with approval by NASA HQ. This additional program reserve prevented an overrun which in the final tally was 97% (29%+68%).

How Good Were The Predictions



The postmortem analysis showed that McRisk underestimated the reserve by 8% (89% predicted vs. 97% actual)

The causes for the 8% underestimate were:

- Staff underestimating the probability of an average risk by 10%
- Staff underestimating the cost of mitigation of an average risk by 20%
- The actual cost of mitigating unknown unknowns was 14% vs. 10% prediction

COMPARISON OF PREDICTED TO ACTUAL RESERVE COMPONENTS

Predicted Risks

Technical Risks 51%		Programmatic Risks	Software	CU*
Mech 11%	Elec 40%	27%	16%	6%

Actual Risks

Technical Risks 58%		Programmatic	SW**
Mechanical 15%	Electrical 43%	34%	8%

•CU - Cost estimation Uncertainty
•**SW -software

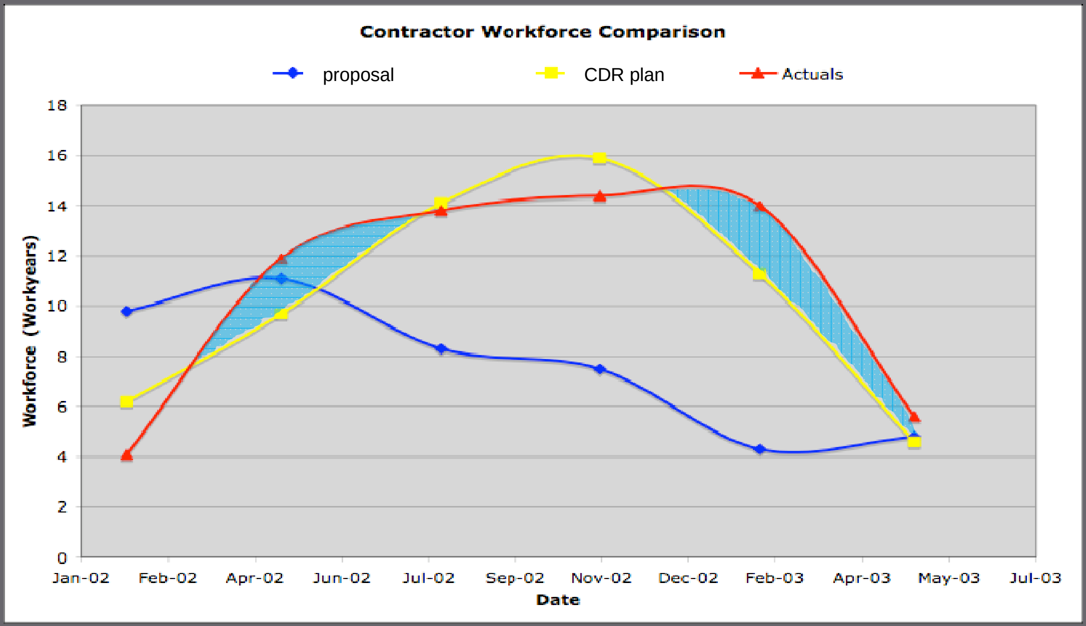
Programmatic Risks are as important as technical risks

Programmatic risks accounted for 34% of all reserve expenditures but they are frequently not included in missions' risk lists. The following risks were correctly identified in the McRisk table for Great Gadget:

- System engineering understaffing
- Allowances for contract mods and adjustments
- Allowances for differences between operations of companies and NASA
- Reviews, action items, contracting pushups-conforming to NASA contractual practices and flight processes
- Launch delays
- Loss of key personnel
- Schedule delays and extension of environmental tests

Workforce Staffing Risk

- A common programmatic risk is the speed of staffing and de-staffing
- The Great Gadget experienced approximately 7% of labor cost growth due to non-optimal staffing as shown on the chart by the light blue area between the red and yellow curves
- Tremendous credit must be given to the contractor that this amount was only 7% despite many starts and stand-downs the project experienced due NASA funding profiles



The Programmatic Ramifications of a Large Reserve

- McRisk not only correctly identified the need for approximately 90% reserve on the cost to go at Confirmation but also allowed to engage the sponsor in factual discussions about risk and the reserve needs.

- Great credit goes to the NASA Program Manager who was very engaged in the reserve discussions and calculations with the project manager. The Program Manager recognized the amount of risk involved in the project and recommended selection of one less experiment in his program to make room for the larger reserve. NASA HQ approved that approach. Without their support the Great Gadget would have become another project that overran available funds despite a cost conscientious contractor.

Conclusions

- The McRisk method of calculating a project's needed reserve allows a statistical estimate of the needed reserve budget to be made that is more consistent with a project's actual developmental risk than existing, more traditional methods.

- McRisk method not only specifies the process for calculation of the reserve but also provides a guide for collecting accurate risk data by using historical information, accounting for cost uncertainty, unknown unknowns, and human psychology that can greatly affect the inputs.

Conclusions

- Even quite accurate reserve calculation methods such as McRisk may not be useful if the Upper Management and sponsors of space projects are not supportive of missions which reveal the true picture of risk and associated costs.

- One way to combat overruns is to reward honest, quantitative and upfront disclosure of risk and discourage “strategic misrepresentation”*, unfounded optimism and simplistic guesses in cost estimating and budget reserve determination.

”Underestimating Costs in Public Works Projects”, APA Journal, 2002, B. Flyvbjerg

Acknowledgments

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